

# **Radiative Transfer Modeling for COBOP**

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## **LONG-TERM GOAL**

The overall goal of this work is to take oceanic radiative transfer theory into a new domain: shallow water with highly variable bottom topography and bottom optical properties, including fluorescent bottom substances.

## **OBJECTIVES**

Currently available models for bottom boundaries invariably assume that the bottom is a Lambertian reflecting surface—a surface that reflects light equally into all upward directions. The objective of this year's work was to quantify the extent to which non-Lambertian bottoms can affect upwelling radiances as would be detected by in-water or above-water sensors.

## **APPROACH**

The HYDROLIGHT 4.0 radiative transfer model (Mobley, 1998; see also <http://www.sequoiasci.com/hydrolight.html>) allows for non-Lambertian bottom boundaries. However, because of the lack of measured Bi-directional Radiance Reflectance Functions (BRRFs; Mobley, 1994) for actual ocean bottom materials, HYDROLIGHT's mathematical capability has never been exploited. In this year's study, analytical models for non-Lambertian BRRFs were used to simulate radiances for situations of interest to the underwater Fluorescence Imaging Laser Line Scanner (FILLS) and the airborne Portable Hyperspectral Imaging Low-Light Spectrometer (PHILLS) systems, both of which play a major role in the CoBOP field programs.

## **WORK COMPLETED**

Although some bottoms (such as sand) may be good approximations to Lambertian reflectors, other bottoms (such as sea grass beds) are very non-Lambertian. In the case of a sea grass bed, for example, a nadir-viewing sensor tends to see the grass leaves "end on" (in calm water), so that the bottom substrate is most visible. Off-nadir viewing angles tend to see the grass leaves from the side, so that the canopy obscures the underlying substrate. The resulting BRRF will be both angularly non-Lambertian, and the color of the reflected light will depend on the viewing angle.

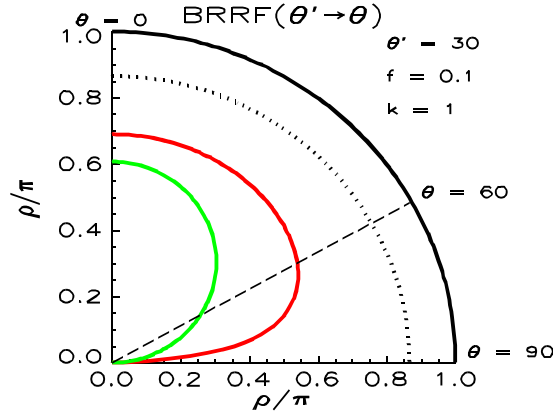
Pending the availability of actual measurements of BRRFs for various bottom types (such measurements are now being made by other investigators as part of the CoBOP program) simple analytical models of non-Lambertian bottom boundaries were used to simulate upwelling radiances within and above the water surface. For example, simple arguments based on light propagation through

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an idealized grass canopy geometry lead to a BRRF of the form

$$BRRF_{\text{grass}}(\theta' \rightarrow \theta, z=H) = \frac{\rho}{\pi} \cos\theta' \exp \left[ \ln(1-f) \left( \frac{1}{\cos\theta'} + \frac{1}{\cos\theta} \right) \right]. \quad (1)$$

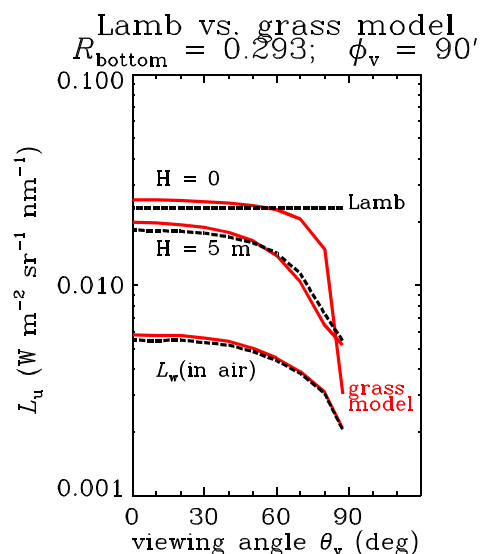
Here  $\theta'$  is the polar angle of the incident radiance,  $\theta$  is the angle of the reflected radiance,  $\rho$  is the reflectivity of the bottom substrate (assumed to be Lambertian), and  $f$  is the fraction of irradiance absorbed by the canopy for light passing straight down through the canopy ( $\theta' = \theta = 0$ ). Figure 1 shows this BRRF compared to a Lambertian reflector, for which  $BRRF = \rho/\pi \cos\theta'$ , and with a BRRF that has been used to model lunar dust.



**Fig. 1. Comparison of BRRFs. The black dotted line is a Lambertian reflector for  $2\theta' = 30$  degrees; the red line is Eq. (1) for  $f = 0.1$ ; the green line is a lunar-dust BRRF.**

## RESULTS

Idealized BRRFs like those of Fig. 1 were used in HYDROLIGHT 4.0 to simulate upwelling radiances for a variety of environmental conditions. Figure 2 shows an example of upwelling daylight radiances for a particular set of water inherent optical properties (based on measurements made in the clear waters of the CoBOP Bahamas 1998 field experiment). The bottom was at 20 m depth. The radiances are shown as a function of nadir viewing angle, at right angles to the sun. The radiance at a height of  $H = 0$  above the grass canopy does not differ greatly from that of a Lambertian bottom of the same irradiance reflectance until the nadir angle is greater than 60 degrees. For a height of  $H = 5$  m above the bottom, there is little detectable difference in the Lambertian and non-Lambertian bottoms, because scattering by the intervening water obscures the bottom effects for large off-nadir viewing angles. In this case, the FILLs sensor would not see much difference in the two bottom types, if all other parameters were the same. The curve labeled “in air” is the water-leaving radiance, which is of interest to the PHILLS sensor. This sensor would see almost no difference in these two bottoms.



**Fig. 2. Comparison of upwelling radiances for a Lambertian bottom vs. a bottom with a BRRF described by Eq. (1). Each bottom has the same irradiance reflectance,  $R = E_w/E_d = 0.293$ .**

Simulations like those of Fig. 2 show that the different *angular* reflectance patterns do not make much difference in the signals received by the FILLs or PHILLs sensors. However, Lambertian and non-Lambertian bottoms can have much different irradiance reflectances  $R$ . Thus the main effect of a non-Lambertian bottom may be its effect on the overall *magnitude* of the upwelling radiance. Additional results are given in Mobley (1999).

## IMPACT/APPLICATION

Inverse models are being developed by other ONR investigators to retrieve bottom depths or bottom classification information from hyperspectral ocean color sensors such as PHILLs. Those retrieval algorithms generally assume the bottom to be a Lambertian reflector. HYDROLIGHT simulations like those in the present work allow the proposed inversion algorithms to be evaluated for non-Lambertian bottom boundaries. This work is underway and will be reported in Mobley (1999).

## TRANSITIONS

Radiative transfer modeling like that outlined above is fundamental to understanding the signals received by the FILLs sensor, or by the related EOIDS sensor, when operated in daylight, elastic-scattering mode. These and similar results have been given to M. Strand of the Naval Coastal Systems Station for use in FILLs and EOIDS system evaluations. Dr. Strand suggested some of the simulations performed in this year's study.

## RELATED PROJECTS

1. As noted in the transitions section, this work is coordinated with M. Strand, who is separately funded by ONR. Our collaboration is directed toward prediction of FILLs system performance when operated in daylight.
2. Measurements of BRRFs for various bottom types are being made by K. Voss, and measurements of

the light field in sea grass canopies are being made by R. Maffione, both of whom are separately funded by ONR. Their data, when available, will be used to replace the overly simple analytical BRRF models (such as Eq. 1) that were used in these initial simulations.

## **REFERENCES**

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